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Longbow Stationary Target Indicator Technical History

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PREFACE

This document was prepared under an IDA Central Research Project titled "Longbow Technical History." It reviews the long-term IDA involvement with this program, particularly the Stationary Target Indicator, based on the fire control radar's high-range-resolution capability.

CONTENTS

I. INTRODUCTION

Late in the Comanche program, the Assistant Product Manager Radar attempted to collect lessons learned from the Operation Iraqi Freedom experience of the Apache Longbow. The Comanche radar was to have been based on very similar technology, so this was a prudent and responsible action. The Comanche representatives conducted interviews with aviators from five Aviation Squadrons and one Cavalry unit and asked for their assessment of Longbow performance. A brief synopsis of their responses is as follows:

- Eighty percent found the system effective or very effective against moving columns of vehicles.
- Two-thirds found it effective or very effective under adverse weather conditions.

However:

- Sixty percent of pilots found the fire control radar performance worse in Iraq than in training/gunnery.
- Half disagreed or strongly disagreed with the statement that the fire control radar helped perform the mission.
- Sixty percent found the false alarms (mostly for stationary targets) excessive.
- Nearly half found the fire control radar unsatisfactory or very unsatisfactory in open terrain.
- A smaller set used the fire control radar in urban terrain, and almost all found it very unsatisfactory.
- More than half of operators lacked confidence in the fire control radar for target-acquisition accuracy.
- The radar was primarily used to fire the semiactive-laser-guided Hellfire missile, not the RF Hellfire.
- The electro-optical/infrared-based Target Acquisition and Designation System was the primary target acquisition sensor for the RF Hellfire missile, rather than the fire control radar designed for this role.
- There were numerous false SA-8 targets.

While the responses above are critical of the Longbow fire control radar, the overall upgrade program for the Longbow Apache (AH-64D) actually provided a major improvement in effectiveness over the original Apache platform (AH-64A). Unfortunately, a great deal of the expense of the upgrade was devoted to attempts to remedy problems with the fire control radar's stationary target indication capability. In the end, these attempts fell short even of the relaxed goals, instead producing a limited capability that at times interfered with the mission (as the comments above suggest). Even more unfortunate, this limitation was foreseen and presented to the Army by IDA early and frequently in the Longbow program history.

This paper provides an overview of the communication interaction between IDA and the Longbow program. Our intent is to understand how to help our sponsors to make better use of analyses and evaluation support in future programs. Improved technical understanding should translate into improved weapon system acquisition. We need to better understand how to make sure that happens.

II. APACHE/LONGBOW PROGRAM ORIGINS

The Apache (AH-64A), and its semiactive laser Hellfire missile were designed with a specific Cold War mission in mind. The war games that were conducted at the time showed that Warsaw Pact forces were capable of a successful breakout into the Fulda Gap region and that NATO forces would not be able to predict where the breakout would happen. The Apache was designed to address this problem. An Apache troop (company-sized unit—8 helicopters) could carry up to 128 Hellfire Missiles—a sufficient number to blunt a breakout and survive by delivering fires from stand-off distances. From their deployed positions, they could very quickly fly to battle and destroy large numbers of vehicles. They could do this much more quickly than fixed-wing assets that were not preassigned, and they could kill many more vehicles than assigned fixed-wing assets. The Apache mission was to stop the bleeding and give the commander time to react.

One of the AH-64A's critical weaknesses was its limited capability in adverse weather. Rain or fog decreased stand-off distances and reduced the ability to guide the Hellfires to target. In addition, despite the stand-off distances, exposure during the long fly-out times of the Hellfire posed a significant survivability problem against Warsaw Pact air defense systems. To deal with these shortcomings a special access program was begun in the 1980s (perhaps earlier) to develop a fire control radar to permit target engagement in adverse weather and accelerate target acquisition under all circumstances. The fire control radar was paired with an RF version of Hellfire to permit fire-and-forget operation to further decrease exposure times and to increase target-servicing rate.

III. IDA AND THE LONGBOW PROGRAM

A. LIGHT HELICOPTER, EXPERIMENTAL INDEPENDENT ASSESSMENT

IDA's first involvement with the Longbow program was as part of a 1987 Independent Assessment on the Light Helicopter, Experimental, which eventually became the Comanche program. The assessment was led by IDA's System Evaluation Division (SED). At this time, Longbow was still a black program. Under the somewhat standard practice for Cost and Operational Effectiveness Analyses, the effectiveness of Longbow was assessed based on the requirements. Since the requirements are a reflection of desired capabilities rather than feasible ones, it should come as little surprise that the Longbow Cost and Operational Effectiveness Analyses result was very positive.

Unfortunately, the Longbow's requirements could not be met in certain scenarios due to technical limitations. One such scenario was the acquisition of stationary targets—a common target of interest in surveillance and reconnaissance missions. Radar detection and classification of stationary targets is quite limited when compared with its detection of moving targets. It is well understood how to separate moving targets from stationary background clutter. It was not then, nor is it now, understood how to detect stationary targets in ground clutter with a surveillance- and fire-control-type radar. The essential weakness of the envisioned Longbow fire control radar was intuited by Dick Legault at the time of the SED analysis. He concluded that the Longbow system had two requirements that appeared technically unachievable: (1) stationary target detection with very few false alarms per scan and (2) identification with very little confusion. Naturally occurring radar clutter would likely be the dominant factor preventing their achievement. Although Legault identified a serious concern, no resources were available at the time to conduct a more rigorous technical feasibility study. Funding probably would not have solved the problem, for any attempt to conduct a study would have likely met "need-to-know" resistance from the then Black Program Office. The office had already refused to divulge the radar frequency on need-to-know grounds. The IDA independent assessment recommended a new-design conventional helicopter as the best approach for the Army's mission.

Army aviation engagement with IDA then shifted from IDA's SED to the Science and Technology Division (STD) because of Army aviation's growing interest in areas outside aerodynamics, such as electro-optical/infrared sensor development and helicopter signature reduction (mostly radar cross section reduction). These technologies were of primary relevance to the Light Helicopter, Experimental/Comanche.

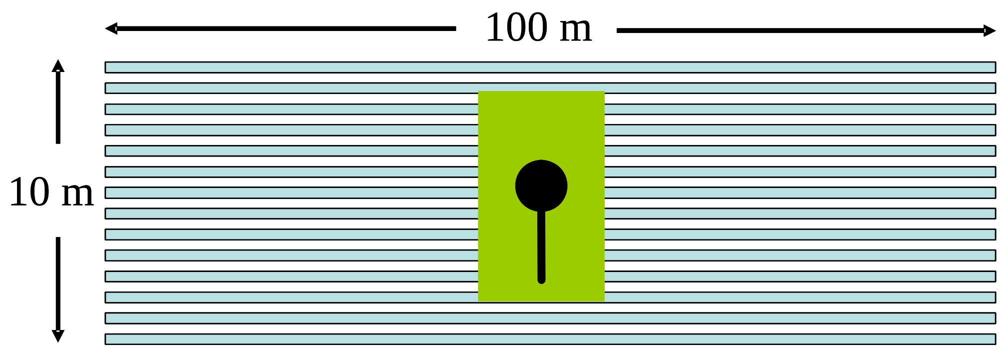
STD pursued development of improved electro-optical/infrared sensors and radar signature reduction with both Army and OSD funding. (Two IDA staff members, Luc Biberman and Dave Sparrow, were named as advisors to the Source Selection Evaluation Board as a result of this work.) The radar cross section work led to a paper on modeling radar clutter, which outlined how models such as JANUS and CASTFOREM should modify their radar-detection algorithms to represent clutter effects more realistically. Originally, the algorithms were designed for noise-limited detection of high-speed, high-altitude, large-cross-section, fixed-wing aircraft. For the purpose of the Light Helicopter, Experimental, the simulation algorithms needed to be modified to apply to clutter-limited detection of low-altitude, low-speed, potentially low-cross-section, rotary-wing aircraft. An essential element of the radar cross section and clutter analyses concerned how the Doppler shift could be exploited to suppress radar returns from stationary clutter, which were much larger than the returns from the moving target. Using the well understood Doppler shift to distinguish moving targets from stationary clutter was a mature technology at this time. The forefront issues related to stationary target detection. Thus, the research interest of IDA was based on how one would distinguish stationary targets from clutter, and process out the clutter.

B. IMPACT OF CLUTTER ON SENSOR PRFORMANCE IN LAND COMBAT

The Longbow program was further along than any others; the Longbow approach used information provided by its high range resolution radar return from the stationary target as opposed to a Doppler-shifted return from a moving target.

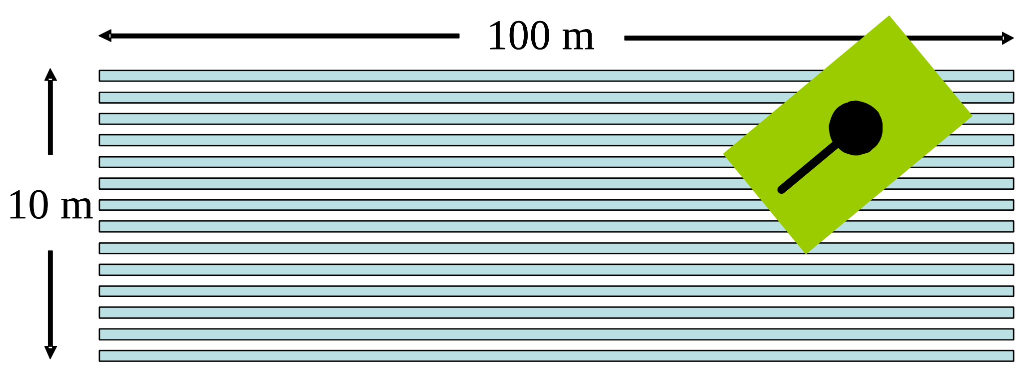
As a follow-on to the work modeling radar clutter for engagement of air targets, STD got a study from the Army's Model Improvement and Simulation Management Agency to look at how clutter affected engagement of stationary ground targets. The Longbow program was at that time further along than any other at trying to exploit high-range-resolution radar signals to do detection and identification of stationary targets. It was selected as the technology development on which to focus.

Tactical radars have low resolution in azimuth and elevation, limited by antenna size. The resolution in range is limited by bandwidth and can be much higher. "High range resolution" means that the radar "pixel" size (in the downrange direction) is small compared with targets of interest. For a Longbow-sized antenna operating in K-Band, with a 1 GHz bandwidth, the radar could distinguish "spots" on the ground about 100 m wide and 15 cm deep. Typically, one would group these range cells, looking for "hot spots," then process the individual cells. A ground patch of about 30 range resolution cells (even numbered cells in blue, odd numbered clear) with a tank in the middle might map like:



The task for the clutter-suppression algorithm is to use the 30 or so returns, called a "range profile," from the wide, thin ground patches to determine whether a target of interest is present. This is very challenging for a number of reasons:

- Each range cell has much more nontarget area than target area. Therefore, the return may not be dominated by the target.
- The target may overlap adjacent patches, either in range or in cross range.
- The target orientation is unknown.
- For a turreted vehicle, the turret chassis angle will be unknown.
- The returns will vary rapidly with viewing angle. For example, there is no reason to believe there will be any similarities in target returns between the situation below and the one above.



Note that in the application of the high-range resolution technique to the air-to-air environment, all these challenges are substantially mitigated or nonexistent.

C. IDA DIRECT INTERACTION WITH THE LONGBOW PROGRAM

The approach taken by the Longbow developers was to create “features” of the returns from various combinations of returns from the different range bins. A notional example might be the sum of the squares of the odd bins minus the sum of the squares of the even bins. If this were large, it would indicate a large cross section, which had a lot of small-scale variability in the return. This might (or might not) be characteristic of a tank, independent of viewing angle. If it were, it would be a candidate to indicate the presence of a tank. Of course, to be useful, these odd-even asymmetries would need to be rare in nature as well as common on tanks. In an attempt to sort targets from clutter, the main engine of the algorithm used 21 features of this sort in the 231 possible linear and bilinear combinations.

In addition, there were several other stages to the algorithm, beginning with a pre-screener that eliminated spots of low return. This was followed by a “heterogeneous clutter filter” designed to minimize the effects of discontinuities in terrain, such as shore lines. The main engine described above was followed by “specialty” algorithms to eliminate “uninteresting” man-made objects (e.g., telephone poles) and finally to classify targets. Unfortunately, there was neither underlying modeling nor systematic measurements to guide these efforts. The developers were left to guess a set of features and “train” on a data set of returns from various vehicles at various orientations at a particular site. The algorithm was then tested on a different data set from the same site. While it was possible to achieve performance that usually met specifications on a given training site, problems quickly emerged.

At this time IDA (Jim Silk and Dave Sparrow) became engaged in the Longbow program’s algorithms working group as part of the clutter modeling task. A major problem was “site dependence”—algorithms only worked at the particular site where they were trained. When the trained algorithms were applied to a different site with different terrain characteristics, they failed.

The proposed solution to the hypersensitivity of the algorithm to the training site was to have a family of algorithms and have the operator select the algorithm developed on terrain that was most like what he saw out his window. Jim Silk proposed that if several versions of the algorithm were to be carried, radar images could be segmented according to terrain type, and different algorithms used in different regions of the radar map. (A version of this idea, called “Adaptive Brain Surgeon” by the Army Research Laboratory, was ultimately incorporated into the design. It provided some limited performance improvement.)

It became clear, however, that site specificity was a manifestation of the brittleness of the algorithms. Further, issues arose about whether other factors needed consideration besides terrain type. For example, were different algorithms needed at a given site, depending on whether or not it rained yesterday?

In short, we became convinced that the Longbow approach to stationary target detection would not meet anything close to the user-required performance. Reasonable detection rates were possible, but the false-alarm suppression was not.

D. THE LONGBOW TRANSCEIVER REVIEW

At the same time that it was becoming clear that the fire control radar stationary target capability was likely to be very limited, DoD attention focused on the missile development. The RF Hellfire missile transceiver power was found to be about 1 dB (26%) below the budgeted number. This led to a high-level Army review, led by the Deputy Assistant Secretary of the Army for Research and Technology. The review included looking at operational impacts in adverse weather against a variety of specified targets. In the end, it was finally noticed that the antenna gain was above its budgeted amount by more than the transceiver shortfall and that the system would slightly exceed specified performance.

E. IDA PARTICIPATION IN THE BOTTOM-UP REVIEW

IDA then participated in the 1993 Bottom-up Review, the precursor to today’s Quadrennial Defense Reviews. This included participation in the Attack and Reconnaissance Helicopter Bottom Up Review, which had a much broader focus than just the Longbow stationary target acquisition.

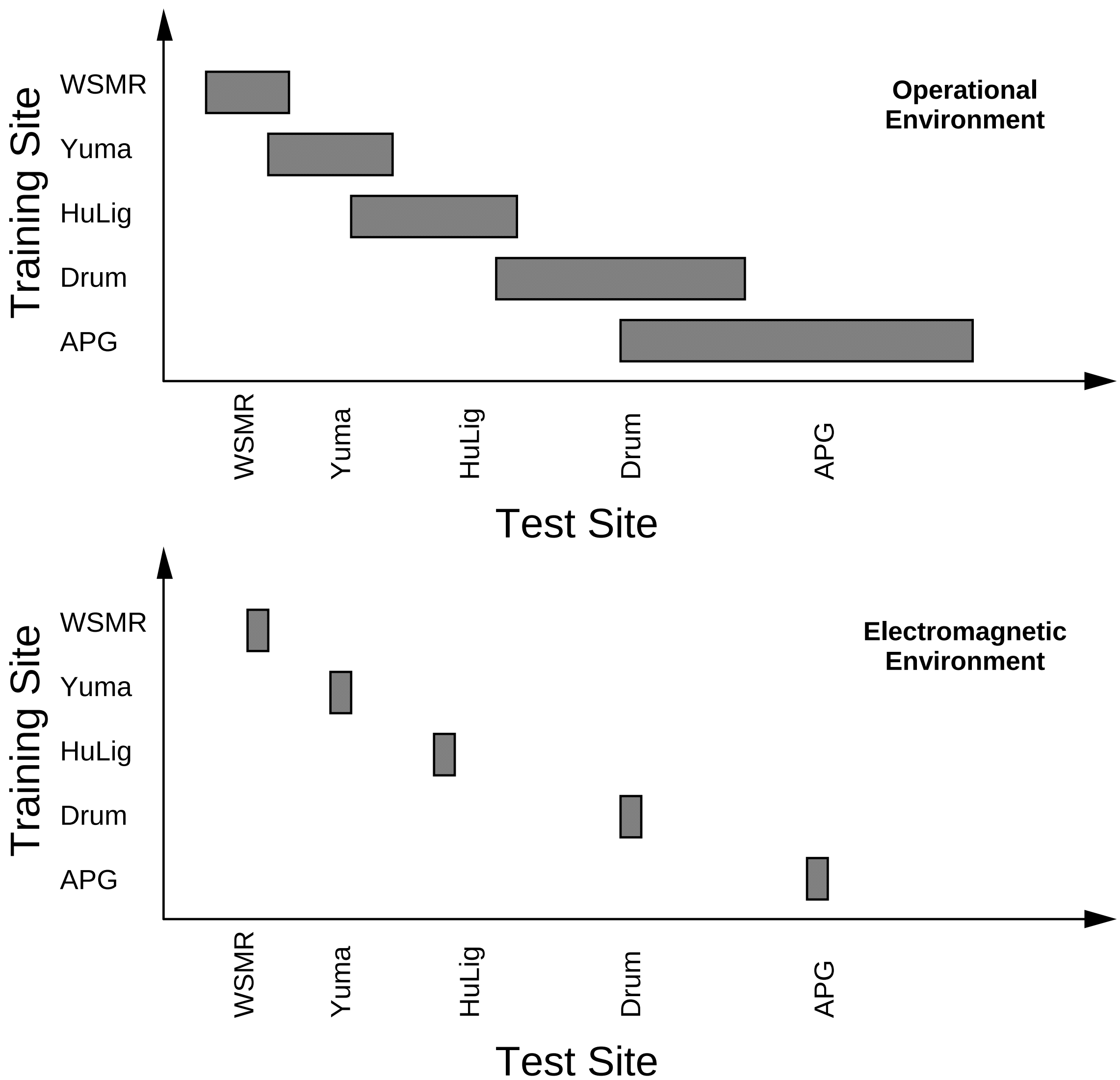
We argued that Army aviation effectiveness against competent air defenses would require a combination of reduced signatures and reduced exposure times. The Longbow system’s design addressed reduced exposure through more rapid search of the battlefield and through use of a fire-and-forget RF Hellfire missile in lieu of the semiactive laser Hellfire. We concluded that the primary exposure time reduction resulted from use of the fire-and-forget missile, which could be used with either the Longbow fire control radar or with a second-generation forward-looking infrared, such as the one planned for

Comanche. Neither candidate was perfect for all scenarios. While the Longbow fire control radar provided some additional exposure reduction against moving targets, it was inferior to the forward-looking infrared against stationary targets. Further, emerging Rules of Engagement were unlikely to permit radar engagement, particularly of stationary targets, without some visual or infrared confirmation. We reported that the Longbow fire control radar approach to stationary target engagement would only rarely be useful: The forward-looking infrared was a better sensor for stationary targets, and it could cue the RF Hellfire missile more accurately than the fire control radar in the stationary target case.[1]

In addition, we argued that there was high risk that the stationary target capability would not meet its then-specified requirement. The Program Analysis and Evaluation (PA&E) sponsor, facing an Army press, requested clarification of our rationale for the assessment. By now we had refined our argument that the performance of the high-range resolution algorithms was so site-specific that it was impossible to know how many data collections (beyond the five that had then been conducted, at great expense) would be needed to ensure that performance to specification could be obtained on an unstudied site.

1 L. Biberman, J. Nicoll, B. Paiewonsky, J. Ralston, J. Silk, D. Sparrow, “Technical Issues in Army Aviation (U)” [Secret/PI], IDA Document D-1393 (Alexandria, VA: Institute for Defense Analyses, July 1993).

Range of Test Sites Where
Performance Exceeds Spec



The training and testing sites had been chosen based partly on what was available, and partly to ensure that there was variability in the sites. The unstated presumption was that the terrain in most places would be at least “sort of like” the terrain at one of the test sites. A set of algorithms, at least one of which worked at each site, would be fairly complete. Based on terrain considerations, the set might be fairly complete, and hence cover the operational environments likely to be encountered. However, radar performance was gong to be determined by the electromagnetic environment—clutter, multipath attenuation, etc. The repeated failures to devise an algorithm at one site that worked at another intuitively suggests that the set is incomplete. We estimated, as part of the bottom-up review report, that more than 10 sites would be needed.

The figure above was designed at the end of the Bottom-up Review to convey the idea that while the Longbow training /test sites were deemed to span the operational environment (upper graph), they do not span the electromagnetic environment (lower graph). There is still no way to know, based on current state of the art, how many sites would be needed to span the electromagnetic environment.

The Program Manager convened a Review Panel to counter our arguments, and we were given only a few hours' notice to reply. Despite our efforts, in the final PA&E Bottom-up Review report, our "high risk" assessment was edited to "risk." After the conclusion of the Bottom-up Review, the stationary target specification was reduced to a level that had already been demonstrated. Thus ended our regular involvement with the Longbow program.

F. IDA ENGAGEMENT OF THE DEPUTY UNDER SECRETARY OF THE ARMY FOR OPERATIONS RESEARCH

But we were not done yet. At this time Marta Kowalczyk had tasking with Walt Hollis, Deputy Undersecretary of the Army for Operations Research, that supported target acquisition modeling. Jim Silk asked Marta for permission to request Mr. Hollis to reallocate some of Marta's funding for a data analysis of Longbow Stationary Target Acquisition test data. Although the thrust of Marta's task was electro-optical/infrared modeling, she graciously agreed. Jim briefly but completely apprised Mr. Hollis of the history described above and requested his support. He, too, graciously agreed to a small allocation.

The objective of this next-to-last gasp was to determine whether the objectives of the Longbow STA effort were achievable in principle. Although some insights were obtained, the end result did not accomplish the goal.

G. IDA (INFORMAL) INTERACTION WITH DOT&E

But we were still not done. In 1995, the Initial Operational Test and Evaluation (IOT&E) for the AH-64D (Apache Longbow) was conducted. As mentioned above, the D model was shown to be much superior to the A model, and this garnered most of the attention. However, the test results also revealed the shortcomings of the fire control radar's ability to detect or classify stationary targets.

The first shortcoming revealed was that the fire control radar classified large numbers of stationary clutter objects as air defense units. This erroneous ID and classification of clutter as very high priority targets concomitantly influenced the free-play portion of the test. (Note: this was reported as fire control radar issue, but it may be a joint fire control radar/radar frequency interferometer problem.)

Another shortcoming was its minimal capability against stationary targets. Understanding how this was revealed requires some knowledge of the tactics, techniques, and procedures. The Longbow missile can use Doppler suppression of clutter to lock onto a moving target while still on the rail, called lock-on before launch (LOBL). The missile cannot lock onto a stationary target at stand-off range, however. Instead, it is fired into a basket and attempts to find and lock onto the target at a much shorter range. This technique is called lock-on after launch (LOAL). The developers anticipated that these two techniques would be standard for moving targets and for stationary targets. There was a third technique: LOBL-inhibit or LOBL-I (also called LOBL-override). This ability to override the LOBL and fire into a basket at a *moving target* was the most common mode used. The pilots routinely used it to minimize their exposure time. Since one of the main advantages of the Longbow system was reduced exposure time, use of this mode was anticipated by IDA, and in our view it should have been anticipated by the Program Office.

In any event, since heavy use of this mode had not been anticipated by the Program Office, developmental testing of the mode had been limited. In the absence of performance data on the LOBL-I mode, data from the other modes were used in the IOT&E scoring. DOT&E raised concerns about test scoring without underlying data on the most common technique used. Hits were scored by matching aim points with target location ground truth, allowing a fairly large separation to be considered a hit. Since there was often a long delay between target detection and firing, this method of scoring would allow credit to be given for hits on targets that would have maneuvered out of the basket.[2] Projected target position based on the fire control radar information at time of impact was compared with the target ground truth. One would expect faster moving targets to have larger discrepancies between the fire control radar prediction and the ground truth. This was the case, with an important exception. Nonmoving “targets” had very large errors. The explanation for this was that the fire control radar was primarily

2 STD had extensive experience with this sort of “proximity”-based scoring from its UXO and mines work.

detecting clutter, and the scoring method was associating the clutter with the nearest stationary target.

Ultimately, DOT&E reported that about 25–30% of the engagements were triggered by clutter. Since most engagements were of movers, this means that essentially all attempts to engage stationary targets involved firing at clutter. Supporting this, approximately 70% of detections reported during the trials could not be correlated with any targets, even though the correlation basket was quite large. (The correlation basket was large compared with either the radar location accuracy or the accuracy of the instrumentation.)

As compelling as this analysis is, it is not the end of the story. Five years later, during Comanche Milestone II tests at Boeing's West Palm Beach plant, Jim Silk made the acquaintance of an Army officer who had been assigned responsibility for the Stationary Target Array deployment for the Longbow Initial Operational Test and Evaluation (IOT&E). He recounted his travails in deploying the armored vehicle target array in 18 inches of standing water, which was the aftermath of unusual rainfall prior to the test. He was enormously relieved that the contractor team agreed to go ahead with the test despite this unusual circumstance, which was considerably outside specified limits.

Of course they did. The radio frequency retro-reflectivity of quiescent standing water in the Longbow fire control radar band is hundreds of times smaller than that of exposed terrain, whether wet or dry. The principal obstacle to fire control radar performance was thus removed form the IOT&E test environment by an act of God. And nobody on the Government side had the combined technical and historical perspective to understand the implications of the situation.

IV. SUMMARY

Experienced analysts with a strong technical background were able to intuit, on first hearing a description of the Longbow program, that performance against stationary targets would be its Achilles heel (1987). This was identified as a research area that STD successfully pursued as part of its sensors and target acquisition focus. The research on the Longbow algorithms revealed the approach to be incapable of delivering needed operational performance (1992). This was stated publicly as part of the Bottom-up Review (1993), as was the fact that a forward-looking infrared could provide adequate target location for the RF missile, thus providing stationary target capability through a different approach. In 1995 the IOT&E revealed the difficulties with detection and classification in a formal test with publicized results. As late as the summer of 2000 we were still discovering the shortcomings of those tests.

In 2003 as part of Iraqi freedom, Apache operators found:

- The system was effective against moving targets and in bad weather.
- False alarms were excessive, especially for stationary targets.
- Most operators lacked confidence in the fire control radar for target location accuracy
- The forward-looking infrared was the primary target acquisition sensor for the RF Hellfire
- There were too many false SA-8 declarations.

To close:

How do we avoid spending money and delaying programs by pursuing features that will not be achieved with the current approach, but are achievable in other ways?

How can we ensure that future operators are not surprised during an operation by what had been intuited 16 years earlier, known with certainty 10 years earlier, and revealed in tests 8 years earlier?

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

This internally funded Central Research Project recounts the technical history of the Longbow program from IDA's initial involvement in 1987 through events reported from Operation Iraqi Freedom in 2003. The upgrade of the Apache to the AH-64 D model is generally accepted as a very successful program. Nevertheless, shortcomings of the fire-control radar's stationary target capability identified and documented throughout the program's history remained unaddressed. Further, these shortcomings, while documented in DoD publications, did not propagate to the operational Army by informing either training or tactics, techniques, and procedures.

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